



Fermi National Accelerator Laboratory

FERMILAB-Pub-79/39-EXP
7160.095

(Submitted to Phys. Rev. Lett)

MEASUREMENT OF HIGH MASS $\gamma\gamma$ AND $\pi^0\pi^0$
PRODUCTION IN 400 GeV/c p Be INTERACTIONS;
A SEARCH FOR η_c

R. M. Baltrusaitis, M. Binkley, B. Cox,
T. Kondo, C. T. Murphy, and W. Yang
Fermi National Accelerator Laboratory, Batavia, Illinois, 60510

and

C. Y. Chien, L. Ettlinger, M. S. Goodman, J. A. J. Matthews,
L. Madansky, J. Nagy, and A. Pevsner
Department of Physics
The Johns Hopkins University, Baltimore, Maryland 21218

July 1980

Measurement of High Mass $\gamma\gamma$ and $\pi^0\pi^0$ Production
in 400 GeV/c p Be Interactions; A Search for η_c

R. M. Baltrusaitis^a, M. Binkley, B. Cox, T. Kondo,
C. T. Murphy and W. Yang
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

and

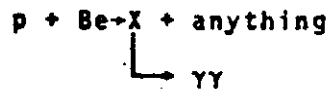
C. Y. Chien, L. Ettlinger^b, M. S. Goodman^c, J. A. J. Matthews,
L. Madansky, J. Nagy^d and A. Pevsner
Department of Physics
The Johns Hopkins University
Baltimore, Maryland 21218

ABSTRACT

A search has been made for high mass narrow states decaying into $\gamma\gamma$ or $\pi^0\pi^0$ in 400 GeV/c p-Be interactions. No significant peaks have been observed in either mass spectra between 2 and 5 GeV/c². We set an upper limit on η_c production at 3 GeV/c² of $\sigma \cdot B(\eta_c \rightarrow \gamma\gamma) < 0.9 \times 10^{-32}$ cm²/nucleon. Cross sections for $\gamma\gamma$ and $\pi^0\pi^0$ production are presented and a comparison with the level of diphotons expected from π^0 and η^0 decay has been made.

A number of $C=+1$ states (e.g. η_c , $\eta_{c'}$, χ_0) of charm-anticharm quarks¹ have been predicted in the mass region 3 to 4 GeV/c², associated with the observed $C=-1$ states, ψ (3.1) and ψ (3.7). The hadronic decays of these states are expected to be suppressed and consequently their mass widths are narrow, thereby enhancing the radiative decay channels such as $C\bar{C} \rightarrow \gamma\gamma$. The DASP group has reported² an enhancement at 2.8 GeV/c² in $\gamma\gamma$ and $\bar{p}p$ final states in e^+e^- interactions, which they attribute to the $\eta_c(2.8)$. Recent e^+e^- colliding beam experiments at SPEAR have yielded³ negative results for this state. However a group at Serpukov has reported a diphoton resonance at a mass of 2.85 GeV/c in the reaction $\pi^-p \rightarrow \gamma\gamma n$ at 40 GeV and more recently a possible candidate for η_c has been reported⁴ at 2.97 GeV by the Crystal Ball at SPEAR.

We have studied the reaction



and looked for narrow states in the $\gamma\gamma$ system. The experiment was performed using a halo-free proton beam⁵ in the Proton West area at Fermilab. The detector^{7,8} consisted of two spectrometer arms, each of which contained a 10 KG-m sweeping magnet, thick steel collimators, 3 layers of lucite hodoscopes, a lead converter, two layers of scintillator hodoscopes and 25 lead glass Cerenkov counters. For this experiment the arms, each of which accepts a solid angle of 2 msterad, were set at a laboratory angle of 6.8° (120° in the center-of-mass system) covering a CM rapidity range of -0.65 to -0.45. A trigger occurred when the total energies deposited in the lead glass arrays of both arms exceeded a threshold requirement and no

charged particles were present in either arm.

Before and after each data taking period, the lead glass elements were calibrated in place with a special electron beam generated in the upstream proton transport⁹. The gain of each lead glass counter was tracked between each electron beam calibration with a hydrogen thyratron flasher system. The position and energy of a photon candidate were determined by fitting the observed fractional energy deposit in each lead glass element to the transverse pattern measured in the electron calibrations¹⁰. This reconstruction method yields a position resolution of $\sigma \approx 0.25''$ for electromagnetic showers.

Typically, 50% of the events show a single energy cluster, and 40% show two clusters in each lead glass array. For events with two clusters in an arm, an invariant mass of the two-gamma system was formed. Typical examples of the mass spectrum of two-cluster events are shown for two different energy ranges in Fig. 1. We see clear π^0 peaks at a mass of 135 MeV/c² which verifies our method of energy and position reconstruction. The solid lines are our estimate of the non- π^0 backgrounds constructed from uncorrelated gammas in the data.

An invariant mass of the diphoton system was computed for events with single gamma rays in both arms. The rate of accidental coincidences was calculated from observed single-arm γ rates and corrected by a spill quality factor which took into account the effect of non-uniform beam spill. The shape of the mass spectrum of accidental coincidences obtained by combining single photon inclusive data from each arm was slightly steeper than the true coincidence mass spectrum. The level of accidentals is approximately 20% of the two photon mass distribution at the low mass end of the spectrum, but is less than

5% of the data above 4 GeV/c². Most of the high mass $\gamma\gamma$ events above 4.5 GeV/c² are due to high energy π^0 's decaying into two gammas which coalesce into a single energy cluster in the lead glass array. We have estimated the shape and absolute level of this coalescing π^0 contribution from the observed $\gamma\pi^0$ coincidence rates multiplied by the π^0 coalescing probability computed by a Monte Carlo method. This coalescing π^0 background is less than 5% of the $\gamma\gamma$ data below 3 GeV/c². Fig. 2 shows the mass spectrum after subtraction of accidental π^0 events. The acceptance for the $\gamma\gamma$ system, the effect of dead time, trigger inefficiencies, and vetoing by charged particles have taken into account. There is no obvious indication of any narrow mass state. We have determined an upper limit of the cross section times branching ratio for a two-photon decay of such a state based on our expected mass resolution ($\Delta m/m \approx 0.06\text{FWHM}$). The solid line in Fig. 2 shows the approximate upper limit of $B \cdot (\frac{d\sigma}{dy})_{y=-0.5}$ at the 90% confidence level. Assuming a linear A dependence, we obtain $B \cdot (d\sigma/dy)_{y=-0.5} < 0.9 \times 10^{-32} \text{ cm}^2/\text{nucleon}$ at the $\gamma\gamma$ mass of 3.0 GeV/c². It is interesting to compare this upper limit with the observed ψ production in pBe interactions, $B(\psi \rightarrow \mu^+ \mu^-) \cdot (\frac{d\sigma}{dy})_{y=0} \sim 0.7 \times 10^{-32} \text{ cm}^2/\text{nucleon}^{11}$. Using a theoretical prediction of the branching ratio $B(\eta_c \rightarrow \gamma\gamma) = 1.4 \times 10^{-3}$ along with an assumed $(1-x)^4$ dependence of η_c production¹¹, we obtain $\sigma_T(\text{pBe} \rightarrow \eta_c + \text{anything}) < 9 \text{ } \mu\text{b}/\text{nucleon}$ for total production cross section of $\eta_c(3.0)$.

We have investigated possible sources of the observed $\gamma\gamma$ mass spectrum. In order to do this we have measured the high mass $\pi^0\pi^0$ spectrum. A π^0 mass cut of $135 \pm 65 \text{ MeV}/c^2$ has been applied for two-

cluster events in both spectrometer arms. The accidental subtraction procedure was the same as that used for the correction of the $\gamma\gamma$ spectrum. False $\pi^0\pi^0$ combinations due to non- π^0 components under the π^0 mass peak (see Fig. 1) were subtracted using coincidence data with the two photon mass outside the π^0 mass cut. Fig. 3 shows the $\pi^0\pi^0$ cross sections corrected for acceptance, trigger inefficiency, and dead time. We also show in Fig. 3 the $\pi^+\pi^-$ mass spectra observed at $y = 0$ in other experiments done at Fermilab¹².

A Monte Carlo calculation based on the observed $\pi^0\pi^0$ spectrum has been made to investigate origins of the observed $\gamma\gamma$ mass spectrum. We also estimated a possible contribution from $\pi^0\eta$ and $\eta\eta$ final states assuming $\sigma(\eta\eta) = \frac{1}{2}\sigma(\eta\pi^0) = \frac{1}{2}\sigma(\pi^0\pi^0)$ as suggested by our measurement of inclusive η/π^0 production⁸. As shown by the dash-dotted lines in Fig. 2, the $\gamma\gamma$ spectrum can be explained by decays of $\pi^0\pi^0(+\pi^0\eta+\eta\eta)$ states in which only one photon from either $\pi^0(\eta)$ is accepted by the spectrometer arms.

In conclusion, we have observed no indication of narrow states in $\gamma\gamma$ (and $\pi^0\pi^0$) final states in the mass range from 2 to 5 GeV/c². The upper limit $B(\eta_c \rightarrow \gamma\gamma) \frac{d\sigma}{dp} < 0.9 \times 10^{-32}$ cm²/nucleon was obtained for the production of η_c at the η_c mass of 3.0 GeV/c². The observed $\gamma\gamma$ continuum can be explained as having its source in the two photon decays of correlated $\pi^0\pi^0$, $\eta\pi^0$, and $\eta\eta$ final states.

We wish to thank the personnel of the Proton Department at Fermilab for their expert assistance. This work was supported in part by U.S. Department of Energy, the Research Corporation, and the National Science Foundation.

- a) Present address: Phys. Dept., Cal. Inst. of Tech.,
Pasadena, CA 91125
- b) Present address: Mitre Corporation, Metrek Division,
McLean VA.
- c) Present address: Phys. Dept., Harvard University,
Cambridge, MA 02138
- d) Present address: Brookhaven National Laboratory,
Upton, NY 11973

REFERENCES

- ¹ For example, T. Appelquist, R. M. Barnett and K. Lane, Ann. Rev. Nucl. Part. Sci. 28, 387 (1978).
- ² W. Braunschweig et al., Phys. Lett. 67B, 243 (1977).
- ³ R. Partridge et al., Phys. Rev. Lett. 44, 712 (1980).
- ⁴ W. D. Apel et al., Phys. Lett. 72B, 500 (1978).
- ⁵ E. Bloom, ibid. They call this candidate U(2976).
- ⁶ B. Cox and C. T. Murphy, Nucl. Inst. and Meth. 136, 35 (1976).
- ⁷ R. M. Baltrusaitis et al., Phys. Rev. Lett. 44, 122 (1980).
- ⁸ R. M. Baltrusaitis et al., Phys. Lett. 88B, 372 (1979).
- ⁹ B. Cox et al., Fermilab TM-765 (1978).
- ¹⁰ R. M. Baltrusaitis et al., IEEE Transaction on Nuclear Science NS 27, 68 (1980).
- ¹¹ H. D. Snyder et al., Phys. Rev. Lett 36, 1415 (1976)
- ¹² R. D. Kephart et al., Phys. Rev. Lett. 39, 1440 (1977) and Fermilab Exp. 357, D. A. Finley, Ph.D. Thesis, Purdue Univ., 1978 (unpublished). The apparent discrepancy between $\pi^+\pi^-$ and observed $\pi^0\pi^0$ cross sections may be explained by a combination of a statistical factor $\pi^+\pi^-/\pi^0\pi^0 = 2$ and a $(1 - |x_F|)^2$ dependence of $\pi\pi$ production as shown in Fig. 3.

FIGURE CAPTIONS

- Fig. 1: Two photon mass spectrum of two cluster events in an arm. (a) $E = 8.9$ GeV (b) $E_{\gamma\gamma} = 15-17$ GeV. The solid lines are the estimates of non- π^0 background caused by uncorrelated gamma rays.
- Fig. 2: Differential cross sections of $\gamma\gamma$ final states at 400 GeV/c. The solid line is the upper limit of narrow resonance in production units of $B \cdot d\sigma/dy \text{ cm}^2/(\text{Be-nucleus})$. Curve (a) indicates the coalescing π^0 contribution to $\gamma\gamma$ based on $\pi^0\gamma$ data. Curve (b) is the Monte Carlo estimate of the $\gamma\gamma$ contribution based on observed $\pi^0\pi^0$ final state. Curve (c) denotes the $\gamma\gamma$ contribution from $\pi^0\eta$ and $\eta\eta$ as well as $\pi^0\pi^0$ final states.
- Fig. 3: Differential cross section at 400 GeV/c for $\pi^0\pi^0$ final states at $y = -0.55$, and $\pi^+\pi^-$ final states at $y = 0$. The dotted line is $1/2(1 - |x|)^5$ times the $\pi^+\pi^-$ cross sections from the experiments of reference 12.

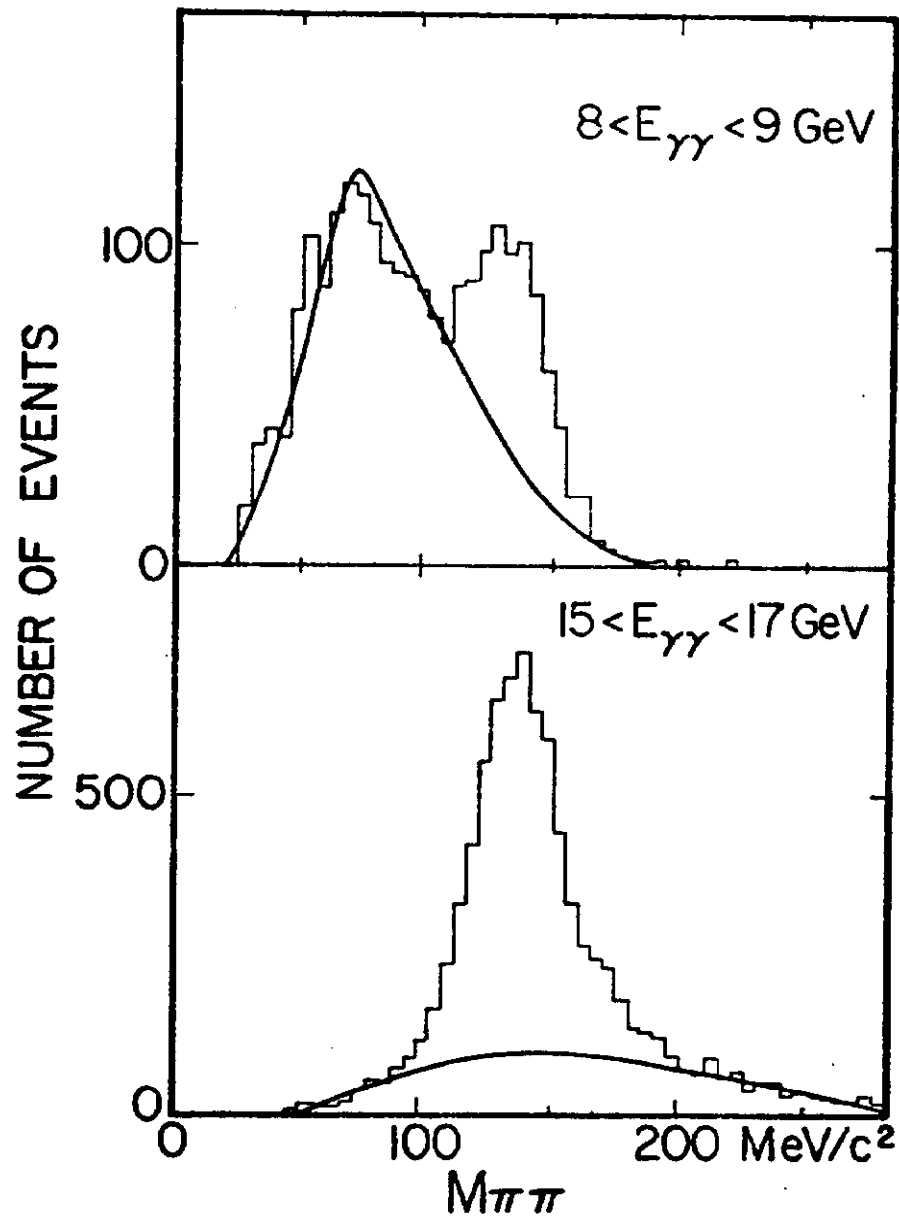


Figure 1

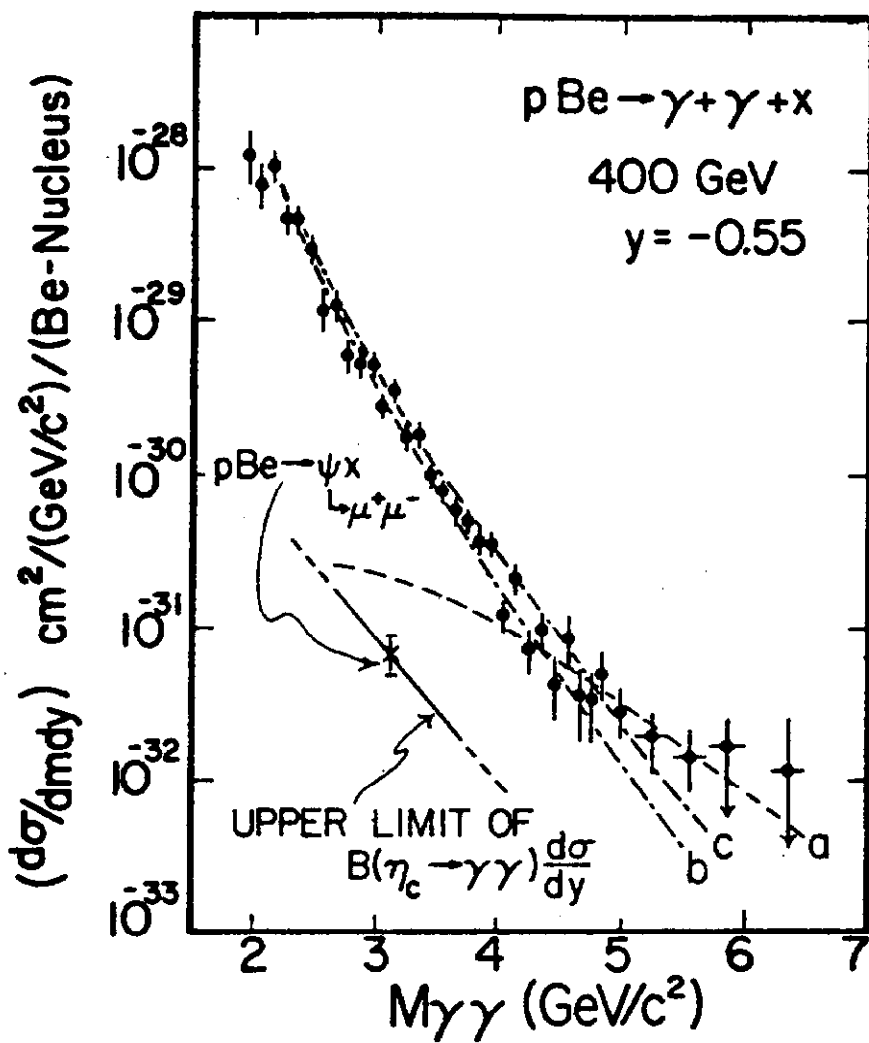


Figure 2

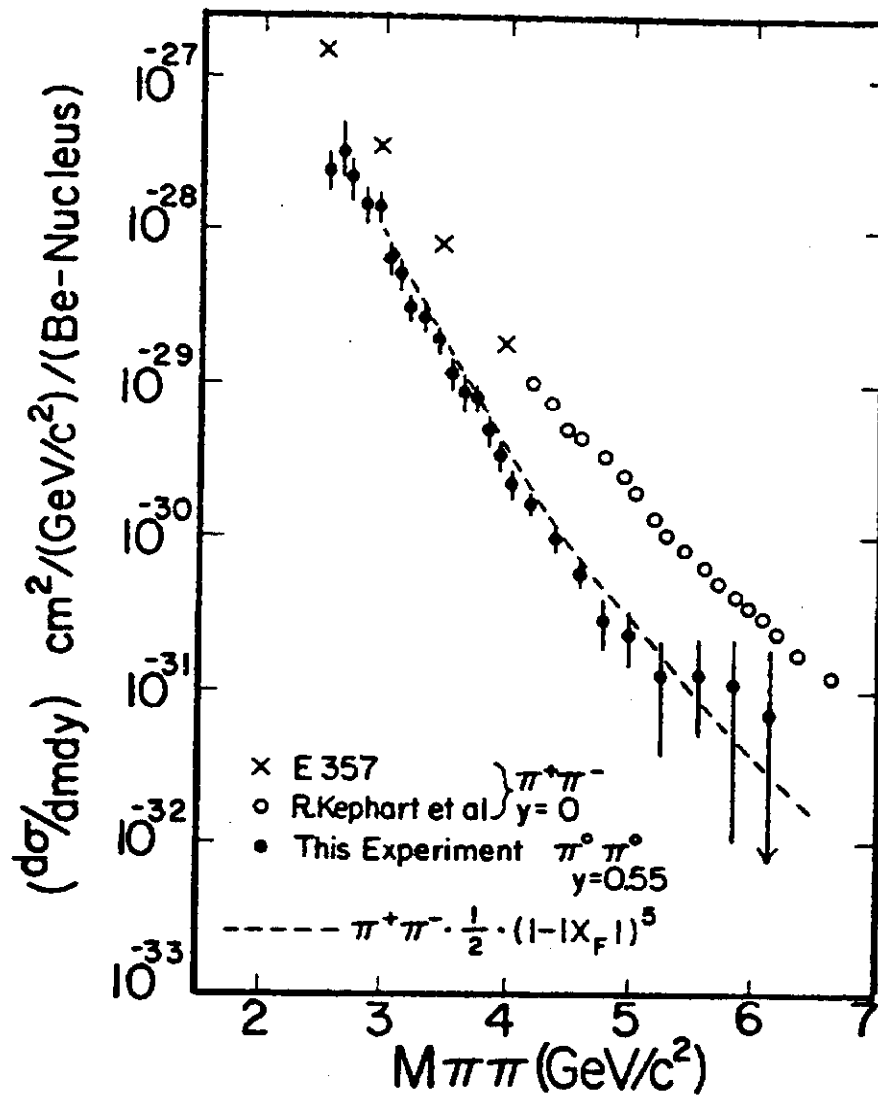


Figure 3